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Development of a comprehensive Blast-Related Auditory Injury Database (BRAID)

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Abstract—The Department of Defense Hearing Conservation Program provides specific guidance for service components to prevent occupational hearing loss; however, it does not specifically contend with the unique noise exposures observed in the theater of war, such as blasts and explosions. In order to examine the effects of blast injury on hearing sensitivity, we developed a large database composed of demographic, audiometric, point of injury, and medical outcome data, with the primary aim of developing a long-standing and integrated capability for the surveillance, assessment, and investigation of blast-related hearing outcomes. Methods used to develop the dataset are described. Encompassing more than 16,500 Navy and Marine Corps personnel, the Blast-Related Auditory Injury Database (BRAID) includes individuals with a blast-related injury and nonblast control subjects. Using baseline and postdeployment hearing threshold data, a retrospective analysis of the cohort revealed that the rate of hearing loss for the injured servicemembers was 39%. The BRAID will be useful for studies that assess hearing patterns following deployment-related injury, such as blast exposures, that facilitate exploration of health outcomes and whether they are predictive of audiometric disposition and that help establish hearing loss prevention strategies and program policies for affected military commands and servicemembers.

Key words: blast exposure, blast injury, Blast-Related Auditory Injury Database, BRAID, hearing conservation, hearing loss, noise exposure, noise-induced hearing loss, occupational hearing loss, servicemembers.

INTRODUCTION

Exposure to hazardous noise, such as constant, intermittent, impact, impulse, blast, or a combination of these, may result in temporary or persistent noise-induced hearing loss (NIHL) and tinnitus. NIHL and tinnitus present a problematic public health burden that has been estimated to affect 22 million Americans [1]. The Armed Forces have engaged Hearing Conservation Programs (HCPs) since the 1960s. This fact should not suggest that the military has mastered the maze of hearing conservation inef-

Abbreviations: AIS = Abbreviated Injury Scale, BRAID = Blast-Related Auditory Injury Database, DMDC = Defense Manpower Data Center, DOD = Department of Defense, DOEHRS = Defense Occupational and Environmental Health Readiness System, DOEHRS-DR = DOEHRS-Data Repository, DOEHRS-HC = DOEHRS-Hearing Conservation, EMED = Expeditionary Medical Encounter Database, HCP = Hearing Conservation Program, HL = hearing level, ICD-9 = International Classification of Diseases-9th Revision, LFPTA = low-frequency pure-tone average, MDR = Military Health System Data Repository, MTF = military treatment facility, NIHL = noise-induced hearing loss, OSHA = Occupational Safety and Health Administration, PTA = pure-tone average, SD = standard deviation, VA = Department of Veterans Affairs.

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ficiencies. To the contrary, military culture adds an additional layer of complication to audiologic management of servicemembers, making avoidance of hearing loss or even slight shifts in hearing sensitivity increasingly difficult. The Department of Defense (DOD) HCP [2] provides specific guidance for service branches in an effort to mitigate occupational hearing loss; however, it does not specifically address unique noise exposures observed in the theater of war. Combat noise exposure, which by military regulation does not mandate hearing protection, is a problem scenario for the hearing conservationist because many of the high-level operational military noises are immutable.

The gold standard method of surveillance for Occupational Safety and Health Administration (OSHA) [3] and DOD HCPs is the audiometric hearing threshold test—the audiogram. Both OSHA and DOD require annual audiograms, also called pure-tone tests, which include test frequencies from 500 to 6,000 Hz. The principal difference between OSHA and DOD is that follow-up testing is required in the DOD system whenever hearing shift has been observed, but follow-up is only recommended by OSHA. Further, most OSHA-based programs apply age-correction in their threshold-shift calculations, but this is not permitted in the DOD because age-correction expunges threshold shift in individuals and thus reduces the sensitivity of audiometric monitoring. Given the migratory nature of combat military personnel, it is imperative to capture audiometric screenings consistently in order to identify hearing shift as early as possible; individuals deployed to battle zones are increasingly at risk for NIHL, tinnitus, and other otologic injuries [4]. The effects of blast exposure on the auditory system are well documented in the literature and suggest varying audiometric outcome patterns [5–9].

The ear is the most susceptible to and often the first organ to sustain blast injury [7,10–12]. Factors such as the position of the ear in relation to the explosion, the state of the ear canal, and whether the explosion occurred in a confined space can influence the severity of damage to the ear [11,13]. The most visible type of blast-induced auditory injuries occur in the physical structures of the middle and inner ear, which include tympanic membrane perforations, ossicular disruptions, and symptoms generated from insult to the vestibular components [5,12,14–17]. Damage to auditory components of the inner ear is of primary interest because it may be permanent and cause persistent symptoms of tinnitus [18–20] and hearing loss [6,17,21–23]. Blast-related middle-ear damage has been associated with perforation of the tympanic membrane, although spontaneous recovery has been observed in the vast majority of injured patients [12,14,24]. Similarly, inner-ear temporary hearing shift caused by blast can improve slightly, but has not been reported to recover as predictably as middle-ear injuries.

The manner in which blast exposure persistently affects hearing sensitivity in the short- and long-term has not been adequately represented in the literature. Most reports have been directed at small samples involving civilian personnel. Several studies have reported minimal sensorineural hearing loss in blast-exposed individuals [5–9,25]; however, reversible conductive hearing losses have been more consistently identified. The greatest source of information on symptoms immediately following primary blast injury of the ear may be found in civilian literature [26]. Blast injury among civilians, however, is uncommon and generally studied as a consequence of terrorism or industrial accidents. Sample sizes in these studies are relatively small, and the prevalence of symptoms among all exposed persons is unknown. Such reports contain primarily descriptive statistics of presenting injuries and symptoms.

Assessing the progression of audiologic symptoms is of primary importance in determining hearing-related morbidity. The most common symptoms reported in victims of blast are tinnitus and hearing loss, with a significant proportion of patients reporting concomitant tinnitus and hearing loss. Cave et al. determined that only 63 percent of their sample of 258 blast-injured patients had a predeployment audiogram and reported that approximately 50 percent of their subjects demonstrated persistent hearing loss [13]. They attributed this higher rate to the fact that their data were extracted from an audiology clinic database. Mrena et al. assessed the otologic and audiologic outcomes of 29 patients treated for ear injury after a Finland shopping mall explosion [27]. They found that 66 percent reported tinnitus as their initial symptom, and 55 percent reported hearing loss. Twelve of the twenty-nine patients (41%) experienced both tinnitus and hearing loss.

It is unclear which of the audiometric patterns reported by investigators [5–9] can be associated with war-related blast outcomes. Lew et al. found that 62 percent of combat Veterans complained of hearing loss, while 38 percent reported tinnitus [7]. It is unknown whether hearing loss and tinnitus in these Veterans is a

result of central auditory pathway disorder [28] or injury to the peripheral auditory system (e.g., cochlear). A number of studies have shown that blast exposure can result in damage to the hearing mechanism, but this is not consistently reflected as hearing loss in audiometric-threshold data, making evaluation of patients using a dual-sensory methodology worthwhile [29–30]. In a study of 250 Veterans, Oleksiak et al. reported that 87 percent of subjects had a complaint about hearing, and when exposed to blast, claimed to have increased auditory problems [31]. Tinnitus was reported in 76 percent of their subjects, while 49 percent had a diagnosis of conductive sensorineural hearing loss or central auditory dysfunction. Subclinical levels of auditory dysfunction were indicated in 24 percent of the sample [31]. Altogether, studies have not been in agreement regarding the frequency of permanent hearing loss and hearing shift rates, but because the majority of these investigations consisted of small sample sizes, it is unclear what the definitive rate of permanent loss is in a large, relatively homogenous sample.

Disability reports from the Department of Veterans Affairs (VA) have estimated that the cost of hearing loss increased more than tenfold from 1994 to 2011 [32], exceeding $1 billion annually. Recent reports have identified tinnitus and hearing loss as the most common VA service-connected disabilities [20,33]. A hearing loss cost-probability model demonstrated that a typical retired operational servicemember would cost the government almost $14,000 for hearing loss over his or her life span [34]. However, the exact cost of compensation for hearing loss and tinnitus is unclear because of the method used to compute VA disability. To compound the problematic nature of this issue, there is a shortage of quality epidemiologic data on adventitious hearing loss in the general population [35].

Our primary aim was to develop a long-standing and integrated capability for the surveillance, assessment, and investigation of blast-related hearing outcomes. Focused on minimizing the limitations observed in previous studies, our immediate goal was to use the database to describe the deployment-injured population with audiometric data in the Defense Occupational and Environmental Health Readiness System (DOEHRS) and determine the rate of hearing loss in this retrospective cohort. Future goals include using the database to track health outcomes and gain an understanding of whether they are predictive of audiometric disposition.

METHODS

Study Population

All Navy and Marine Corps personnel who had a deployment-related injury captured in the Expeditionary Medical Encounter Database (EMED), a deployment confirmed by the Defense Manpower Data Center (DMDC), and at least one valid audiogram in the DOEHRS-Data Repository (DOEHRS-DR) database from 2001 to 2013 were included in the Blast-Related Auditory Injury Database (BRAID). The EMED has been described in detail elsewhere [36]. Briefly, the EMED provides clinical data across the spectrum of medical care delivered in the operational setting. All available audiometric data for injured sailors and marines were extracted from the DOEHRS-DR database, which is discussed in detail in the next section. Relevant demographic, military, and health information was extracted from the DMDC database and the Military Health System Data Repository (MDR). The DMDC is the central source for identifying information on military personnel and was used to gather demographic and service-related information (https://www.dmdc.osd.mil/). The MDR is the centralized data repository that captures, archives, validates, integrates, and distributes DOD healthcare data. Data are received from DOD's worldwide network of more than 260 healthcare facilities and also from non-DOD data sources (http://www.health.mil/).

There were 18,250 Navy and Marine Corps personnel with coded deployment injuries in EMED. Only 3 percent (n = 525) had no recorded audiograms in the DOEHRS-DR. Compared to the group with audiograms, this group consisted of significantly more Reserve/National Guard members (68% vs 14%, $p < 0.001$), who were generally older, of higher rank, and a higher percentage of Navy personnel. After excluding those with no audiograms (n = 525) and deaths (n = 512), there were 17,213 subjects with 56,010 audiograms between 2001 and 2013 in the DOEHRS-DR system. A total of 4,494 (8%) of the audiograms were classified as unreliable, inaccurate, or associated with middle-ear obstruction and were removed based on our exclusion criteria outlined in the next section, resulting in the removal of another 688 subjects. The remaining 16,525 subjects represented 51,516 audiograms, 96 percent (16,525/17,213) of the original subjects and 92 percent (51,516/56,010) of the composite of audiometric records.

Audiometric Data

The Navy and Marine Corps Public Health Center provides oversight of the DOEHRS-Hearing Conservation (DOEHRS-HC) and DOEHRS-DR (www.med.navy.mil/sites/nmcphc). Personnel who are eligible and enrolled in the HCP are tested annually by certified Navy Hearing Conservation Technicians in certified single- or multisubject acoustic test enclosures. Pure-tone air conduction testing is administered using TDH-39 supra-aural headphones (Telephonics Corporation; Farmingdale, New York) connected to a Benson Medical Instruments CCA-200 computer-driven audiometer (Benson Medical Instruments; Minneapolis, Minnesota), which is acoustically calibrated annually [37]. Audiometers receive a daily functional check and biological calibration using the BAS-200 simulator (Benson Medical Instruments). Daily calibration data are stored in DOEHRS-HC or printed for periodic compliance inspections. Subjects respond to pure-tone stimuli using a hand switch. Threshold data are collected in CCA-200 and transferred by the technician to the DOEHRS-HC software for storage, printing, and upload to the DOEHRS-DR. After the hearing test, personnel are counseled on findings and scheduled for a confirmation retest whenever hearing shift or baseline revision is indicated. Otoscopic visual inspection of the ears is conducted at the discretion of the HCP clinic supervisor, typically after a threshold shift or hearing loss is evident on the audiogram and whenever a referral is indicated.

The DOEHRS-DR provided all audiometric test dates and hearing thresholds for left and right ears at six test frequencies: 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hz [37]. Problematic audiometric data were excluded from the database. Missing hearing thresholds, data entry errors, and indications of "no response" resulted in removal of the subject's entire audiogram, both left and right ear data. Hearing thresholds with interaural differences of 50 dB or more resulted in exclusion of the affected audiogram because these disparities require special consideration, such as clinical referral for masking. When thresholds were greater than 20 dB on the hearing level (HL) scale (dB HL) and exhibited a ratio of low-frequency pure-tone average (LFPTA; 500–2,000 Hz) over high-frequency pure-tone average (PTA) (3,000–6,000 Hz) that was $\geq$1.5 for the same ear, the subject's audiogram was disqualified because this configuration would not be associated with hazardous noise exposure. A low-to-high-frequency PTA ratio of 1.5 or greater indicates that 500–2,000 Hz thresholds are markedly poorer than 3,000–6,000 Hz thresholds, which is consistent with a low-frequency middle-ear problem. Audiograms with an absolute value LFPTA difference between ears that exceeded 45 dB were excluded for the same reason. For example, if the left ear LFPTA is 20 dB and the right ear LFPTA is 70 dB, the absolute value difference would be 50 dB, which may point to audiometric masking, unreliable data, conductive hearing loss, or other conditions unrelated to noise exposure. If a subject had multiple hearing tests recorded on the same day, only one audiogram was retained and all other test data for that date were excluded. To retain the most pertinent audiogram of the day, we used the DOEHRS-DR numeric classification, which effectively captures the purpose of each hearing test. Quality assurance checks were performed, and 100 percent of excluded audiograms were reviewed by a licensed and certified audiologist and Council for Accreditation for Occupational Hearing Conservation Professional Supervisor of the Audiometric Monitoring Program to ensure adherence to exclusion criteria for problematic DOEHRS-HC threshold data.

Injury Data

The EMED is designed to collate information from multiple points of care for each subject, beginning on the battlefield and contiguous battalion aid stations and culminating with military treatment facilities (MTFs) that provide tertiary care [38]. Variables contained in the EMED include date of injury, Abbreviated Injury Scale (AIS) score, Injury Severity Score, mechanism of injury (e.g., blast, gunshot wound), description of injury, and International Classification of Diseases-9th Revision (ICD-9) code of clinical diagnosis. Demographic and military-specific variables included in the database are service branch, rank, occupational specialty, sex, and date of birth. Follow-up inpatient and outpatient medical data were obtained from the MDR, which provides observations from DOD MTFs and TRICARE-approved service providers. Diagnostic information was represented by ICD-9 codes extracted from each subject's electronic health record. After matching the EMED and DOEHRS-DR data, we conducted an extensive examination of hearing threshold and health outcome data recorded before and after injury.

Statistical Analyses

Hearing outcomes were calculated from the audiometric data using standard clinical definitions and the

experience of a senior occupational audiologist. Severity, type, and site of injuries incurred by the study population were compared by battle and nonbattle injury using chi-square statistics. Data analysis and management were performed using SAS, version 9.3 (SAS Institute Inc; Cary, North Carolina).

RESULTS

Table 1 is a display of the demographic characteristics of subjects with reliable audiometric data. Our study population of injured servicemembers with available audiometric data was predominantly male (97%) and enlisted in the Marine Corps, with a mean ± standard deviation (SD) age of 24.0 ± 5.7 yr at the time of first-recorded injury. The majority (95%) of subjects were pre-presbycusic, classified as ≤36 yr. More than 93 percent of the group was enlisted, primarily midlevel and junior enlisted personnel. Occupationally, the distribution of infantry and noninfantry personnel was equivalent, and tinnitus was reported at a rate that was similar to what is observed in the general population.

Figure 1 demonstrates that the majority of the sample (67%) had from one to three audiograms in the DOEHRS-DR. Remaining subjects (33%) had between 4 and 19 audiograms on record. This produced a right-skewed distribution, with a median of two audiograms. **Figure 2** indicates that over the 12 yr period of this investigation, 89 percent of the personnel who went into the combat zone and recorded an injury there had an audiogram in DOEHRS-DR from prior to their injury. Over this same period, 70 percent of the sample had an audiogram in the DOEHRS-DR from after their injury. The diagram shows that almost 60 percent of the sample had both a pre- and postinjury audiogram in the DOEHRS-DR and more than a third of the group had multiple audiograms in the DOEHRS-DR from after their injury date.

The BRAID cohort had a mean ± SD of 2.7 ± 3.4 injuries overall per individual. All medically documented injuries are shown in **Table 2** by type of injury (battle vs nonbattle). Slightly more than half the cohort had at least one injury on record, and 14 percent had five or more. Not unexpectedly, battle and nonbattle injuries were significantly different by site, type, and severity. Battle injuries were mostly caused by blasts (78%; data not shown) and consisted primarily of open wounds to the head, neck, face, and limbs and internal organ injuries such as traumatic brain injury. Nonbattle injuries were mostly upper- and lower-limb injuries such as strains, sprains, and contusions. The majority of injuries in the battle injury and

Table 1.
Characteristics of deployment-injured Navy and Marine Corps personnel included in the Blast-Related Auditory Injury Database with audiometric data from 2001 to 2013 (N = 16,525).

Characteristic	*n*	%
Male	16,025	97.0
Female	500	3.0
Age at Time of Injury (yr)*		
<21	3,918	23.8
21–28	9,814	59.5
29–36	1,877	11.4
37–44	698	4.2
>44	175	1.1
Pay Grade		
E1–E3	3,273	19.8
E4–E6	10,840	65.6
E7–E9	1,244	7.5
Officer	1,123	6.8
Unidentified	45	0.3
Occupation		
Noninfantry	8,801	53.3
Infantry	7,724	46.7
Service Branch		
Marine Corps	15,046	91.1
Navy	1,479	9.0
Service Component		
Active Duty	14,164	85.7
Reserves/National Guard	2,361	14.3
Battle Injury		
None	8,588	52.0
≥1	7,937	48.0
Number of Injuries†		
1	8,911	53.9
2–4	5,371	32.5
≥5	2,243	13.6
Tinnitus‡		
No	14,245	86.2
Yes	2,280	13.8

*43 missing date of injury.
†Number of injuries overall per person, resulting from ≥1 injury events during deployment.
‡Any in-theater medical record or inpatient or outpatient medical visit with tinnitus diagnosis from 2001 to 2013 (ICD-9 diagnostic codes 959.09, 388.3, 388.31, or 388.32 or AIS code 240205.1).
AIS = Abbreviated Injury Scale, E = enlisted, ICD-9 = International Classification of Diseases-9th Revision.

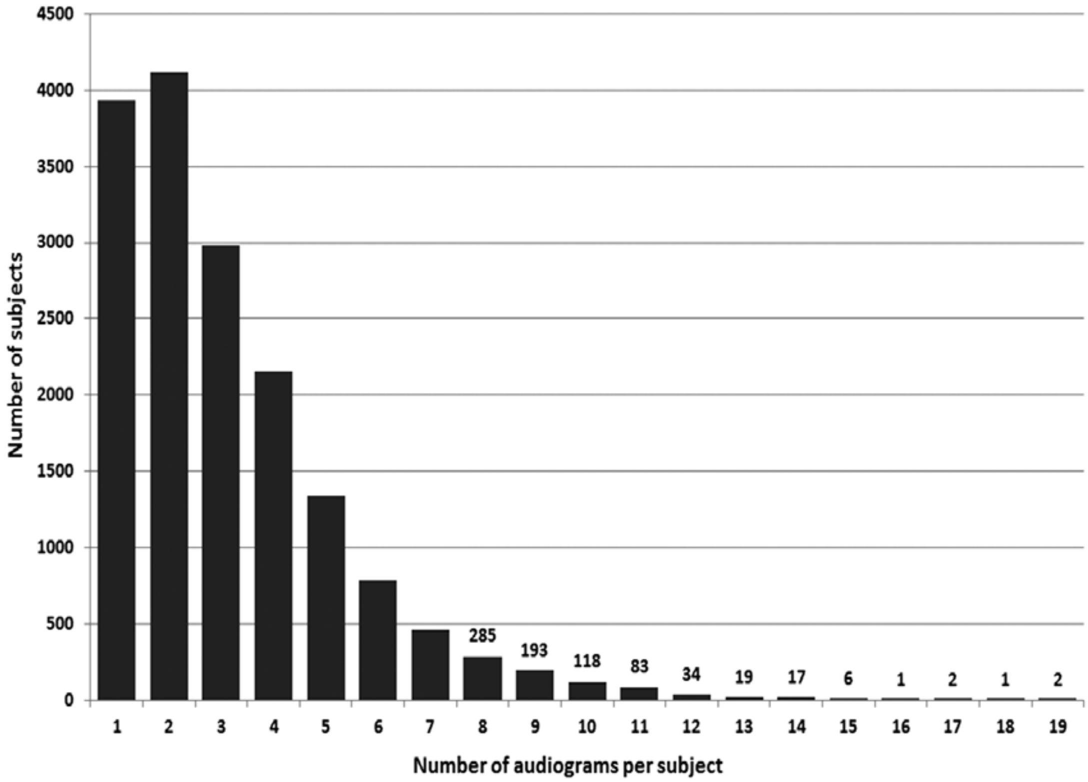

Figure 1.
Distribution of the count of qualified audiometric records per subject.

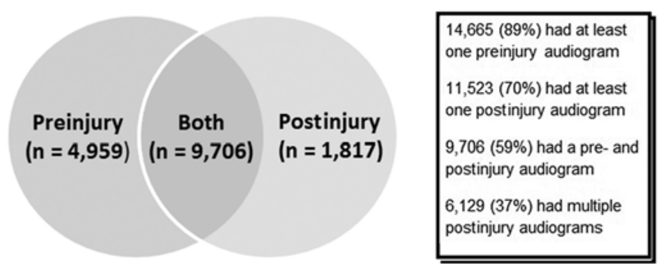

Figure 2.
Frequencies and proportions of deployment-injured Navy and Marine Corps personnel in the Blast-Related Auditory Injury Database with pre- and postinjury audiograms (N = 16,482; 43 subjects were missing injury date and could not be included in the Venn diagram).

nonbattle injury groups consisted of minor to moderate injuries as defined by the AIS (90% vs 98%); however, nonbattle injuries were significantly less severe, with less than 2 percent of injuries classified as serious or worse compared with 10 percent for the battle-injury group.

Examination of the hearing threshold data in the BRAID, regardless of injury time, generated a description of hearing loss laterality, severity, and configuration (**Table 3**). Among those injured servicemembers with qualified audiometric data (n = 16,525), 39 percent of subjects demonstrated hearing loss on at least one of their audiograms, 19 percent showed bilateral hearing loss, and 13 and 7 percent had left- and right-unilateral hearing loss, respectively. Using PTA calculations, low-frequency

Table 2.
Descriptive statistics of all 42,034 deployment injuries incurred by 16,525 servicemembers included in the Blast-Related Auditory Injury Database.

	Battle Injuries (N = 29,556)				χ^2
	n	**%**	***n***	**%**	***p*-Value**
AIS Severity†					<0.001
Minor	19,341	68.0	8,594	84.8	
Moderate	6,317	22.2	1,376	13.6	
Serious	2,070	7.3	130	1.3	
Severe	475	1.7	26	0.3	
Critical	246	0.9	7	0.1	
Injury Type‡					<0.001
Fractures	4,186	14.7	997	9.8	
Dislocation	271	1.0	320	3.2	
Sprains and Strains	1,205	4.2	4,144	40.8	
Internal Organ	5,129	18.0	503	5.0	
Open Wound	8,978	31.5	1,481	14.6	
Amputations	478	1.7	26	0.3	
Blood Vessels	607	2.1	16	0.2	
Superficial/Contusion	3,669	12.9	1,962	19.3	
Crushing	7	0.0	16	0.2	
Burns	1,065	3.7	400	3.9	
Nerves	830	2.9	181	1.8	
Unspecified	1,958	6.9	35	0.3	
System-wide and Late Effects	129	0.5	85	0.8	
Injury Site§					<0.01
Traumatic Brain Injury	4,345	15.3	458	4.5	
Other Head, Neck, Face	7,807	27.4	1,281	12.6	
Spinal Cord	54	0.2	7	0.1	
Vertebral Column	1,203	4.2	1,286	12.7	
Torso	3,081	10.8	446	4.4	
Upper Limb	5,369	18.9	3,430	33.8	
Lower Limb	5,940	20.9	2,792	27.5	
Other and Unspecified	555	2.0	378	3.7	
Systemwide and Late Effects	129	0.5	85	0.8	

*Training injuries, accidents, and other noncombat injuries.
†3,452 injuries missing or undetermined AIS severity.
‡3,356 injuries could not be classified because of missing ICD-9 diagnosis.
§3,388 injuries could not be classified because of missing ICD-9 diagnosis.
AIS = Abbreviated Injury Scale, ICD-9 = International Classification of Diseases-9th Revision.

hearing loss was identified in approximately 9 percent of the study population, while high-frequency hearing loss was evident in almost 22 percent of these subjects. There was a higher percentage of high-frequency hearing loss in the left ear (9.2%) than the right ear (4.6%). PTAs were significantly higher in the left ear than the right ear ($p < 0.001$), and high-frequency PTAs were significantly higher than low frequencies for both ears ($p < 0.001$). Subjects with low-frequency hearing loss predominantly had bilateral hearing loss (46%) or loss in the left ear only (33%), and personnel with high-frequency hearing loss showed a preponderance of unilateral impairment (63%), with unilateral left-ear hearing loss evident in 42 percent of those with high-frequency loss (percentages derived from **Table 3**).

DISCUSSION

The purpose of this study was to develop a long-standing and integrated capability for the surveillance, assessment, and investigation of blast-related hearing outcomes. At the

Table 3.
Hearing loss and other outcomes calculated by available audiometric data from 2001 to 2013 of deployment-injured Navy and Marine Corps personnel (N = 16,525).

Outcome	*n*	%
None	10,056	60.9
Any	6,469	39.1
Bilateral	3,187	19.3
Left Ear Unilateral	2,070	12.5
Right Ear Unilateral	1,212	7.3
Low-Frequency Hearing Loss (>25 dB LFPTA*)		
None	15,102	91.4
Any	1,423	8.6
Bilateral	653	4.0
Left Ear Unilateral	470	2.8
Right Ear Unilateral	300	1.8
High-Frequency Hearing Loss (>25 dB HFPTA†)		
None	12,889	78.0
Any	3,636	22.0
Bilateral	1,356	8.2
Left Ear Unilateral	1,520	9.2
Right Ear Unilateral	760	4.6

Note: Any = hearing loss on any audiogram including baseline, predeployment, or postdeployment audiogram.
*Low-frequency pure-tone average (LFPTA) based on the average of the first three frequencies (500, 1,000, and 2,000 Hz) of all valid audiograms.
†High-frequency pure-tone average (HFPTA) based on the average of the last three frequencies (3,000, 4,000, and 6,000 Hz) of all valid audiograms.

time of this report, the BRAID was composed of primarily male, junior to midlevel enlisted, Active Duty Marine Corps personnel. After matching EMED and DOEHRS-DR data and removing audiograms that met exclusionary criteria (4%), 92 percent of the original audiograms were retained, thus our database comprised 51,516 audiograms from 16,525 servicemembers. This retention rate compares favorably with a large prevalence study conducted by Masterson et al. that retained 74 percent of the original test data [39]. Development of the BRAID identified that approximately 97 percent of deployment-injured Navy and Marine Corps personnel had at least one audiogram in the DOEHRS-DR system. A total of 89 percent of our cohort with an injury had preinjury audiometric tests available in the DOEHRS-DR system and 70 percent had postinjury data, providing us a large sample set of injured servicemembers with audiograms for future analysis. For comparison, a study conducted by Cave et al. indicated that 63 percent of their sample of 258 blast-injured patients had a predeployment audiogram [13]. Given the noise hazards prevalent in combat settings, it is critical that deployers obtain a monitoring audiogram before and after deployment.

Our findings on causality and types of battle injuries are consistent with other studies [7,40–42]. In general, the most common audiologic symptoms reported in victims of blast are tinnitus and hearing loss, with a significant proportion of patients reporting concomitant tinnitus and hearing loss. The rate of documented self-reported tinnitus in the BRAID was 13.8 percent, which approximates the national rate of 10 percent [43], and is far lower than the tinnitus rates reported in other blast-exposure studies. Assessing progression of audiologic symptoms is of primary importance in determining hearing-related morbidity. Previous studies have reported variable, but generally higher, rates of combat and blast-related hearing loss when compared with the BRAID. For example, in an investigation of deployed military personnel, Cave et al. found that approximately 50 percent of their subjects demonstrated persistent hearing loss [13]. These investigators attributed this higher rate to the fact that their data were extracted from an audiology clinic database. Previous studies have analyzed definitive clinical data, whereas we have examined occupational hearing conservation screening data. Military and civilian otologic and audiometric outcome data are inherently different, primarily because of the putative penultimate circumstance of the blast [26].

It is difficult to compare studies because some report the number of subjects, the number of ears, or both, and a variety of audiometric interpretations of "normal hearing" have been used. Our investigation identified a rate of hearing loss of 39 percent using octave-band audiometric threshold data, and a clinical definition of normal hearing as ≤25 dB HL at all frequencies. Our hearing loss rate decreased from 39 to 23 percent when PTA threshold data instead of individual frequency threshold data were used as a clinical metric (for low and high frequencies). Our PTA rate (23%) was similar to the national estimate of hearing loss (20%) in the population reported by Lin et al. [44]. A need for further expansion and exploration of the BRAID is indicated.

Study Strengths

The EMED serves as a comprehensive, deployment-health database that contains records of forward-deployed military personnel who receive medical treatment in theater for combat-related injury, noncombat injury, disease, psychiatric conditions, and routine care

[36,42,45]. The EMED is both retrospective and prospective; however, its inclusion of accurate dates of injury provides a platform for prospective studies on hearing loss outcomes of blast injury, including establishment of preinjury baseline and temporality. The BRAID is an extensive database with large applications to many areas of future research in the occupational hearing health of military personnel. Baseline audiograms and multiple follow-up audiograms will allow for the surveillance of hearing shifts and observation of symptom patterns over time. The prospective nature of career, medical, and audiometric data of military personnel is a major strength because temporal associations of exposure and outcome relationships can be established. Subjects with multiple audiograms will provide data for further analyses of audiometric outcomes in future investigations. The large sample size of the BRAID affords sufficient power to detect differences in subgroups in future studies. Given that the permanent characteristics of auditory injury cannot be established until 1 yr after a blast-exposure event [9], the BRAID may be the first large dataset with prognostic audiometric viability. In addition, inclusion of additional personnel records may provide researchers the ability to adjust for multiple confounders.

Study Limitations

In this data manipulation, we could not control for confounders such as cochleotoxic medications, exposures to ototoxic chemicals, recreational noise exposure, and other forms of temporary and persistent threshold shift. Combat marines and sailors are required to qualify with various firearms prior to and, in some cases, during deployment, regardless of military occupation code. It is challenging to confirm the protected exposure levels of subjects and the frequency of exposures on the firing range. This condition may serve as a confounding variable for audiometric threshold data. No Army or Air Force data were available for analysis, and no audiometric data were included that characterize hearing for Veterans following separation or retirement. In addition, the EMED only includes injury records for servicemembers who present for care.

CONCLUSIONS

The deployment setting represents an unusual work environment that introduces risks to the hearing health and safety of military personnel. It is apparent that DOD directives should be revised to include guidance regarding combat noise exposure, requirements for audiometric screening immediately before and after combat operations, and funding for hearing loss prevention. A prudent set of recommendations for combat-inclusive HCP administrators was published by Abel [46]. Hearing preservation research was identified as a top seven research initiative for the Surgeon General of the Navy Bureau of Medicine and Surgery during the Military Health System Research Symposium in August 2012. In the same year, at an annual DOD Hearing Center of Excellence meeting, epidemiologic investigations of military populations were specified as a significant research gap. We anticipate that the BRAID will have multiple applications, including to (1) examine audiometric data pre- and post-blast injury event to discover associated hearing outcomes; (2) refine our framework for quality control of audiometric data; (3) bolster audiometric early flags for combat-related hearing loss; (4) determine health factors that predict threshold shifts and the degree to which symptoms resolve or continue over time; and (5) answer other important research questions about hearing loss, blast exposure, hearing protection performance, and the combined effect of these variables on situational awareness in the field of battle.

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14. ABSTRACT
The Department of Defense Hearing Conservation Program provides specific guidance for service components to prevent occupational hearing loss; however, it does not specifically contend with the unique noise exposures observed in the theater of war, such as blasts and explosions. In order to examine the effects of blast injury on hearing sensitivity, we developed a large database composed of demographic, audiometric, point of injury, and medical outcome data, with the primary aim of developing a long-standing and integrated capability for the surveillance, assessment, and investigation of blast-related hearing outcomes. Methods used to develop the dataset are described. Encompassing more than 16,500 Navy and Marine Corps personnel, the Blast-Related Auditory Injury Database (BRAID) includes individuals with a blast-related injury and nonblast control subjects. Using baseline and postdeployment hearing threshold data, a retrospective analysis of the cohort revealed that the rate of hearing loss for the injured servicemembers was 39%. The BRAID will be useful for studies that assess hearing patterns following deployment-related injury, such as blast exposures, that facilitate exploration of health outcomes and whether they are predictive of audiometric disposition and that help establish hearing loss prevention strategies and program policies for affected military commands and servicemembers.

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combat, blast injury, military, hearing loss, auditory outcomes, tinnitus, OEF, OIF

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